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Is there a space for additional renewable energy in the Norwegian power system? Potential for reduced global emission?

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ABSTRACT

This paper presents the results of a Norwegian power system analysis. An energy system analysis model based on linear programming is used for modelling and optimisation. The analyses cover a number of scenarios where the studied system is subjected to changes by introducing other renewable energy sources, energy conservation measures and measures to promote renewable energy. The study shows that due to a combination of cheap hydropower and high investment costs, it is quite difficult for new generation units to be profitable. This is also true during periods of low precipitation where the system tends to survive on imported power instead of investing in new generation units. However, this does not apply to energy conservation measures that easily enter the system. On the other hand, biomass based CHP, wind power and wave power could be viable if measures are introduced to promote their use. Most of the scenarios show a high potential for reducing global emissions.

Contents

1. Introduction

Diverse human activities over hundreds of years have caused the concentration of greenhouse gases (GHG) to reach levels where measures are necessary to avoid negative consequences from climate change. It is a known fact that most of the world's primary energy supply is based on fossil fuels and their combustion is the main source of global CO_2 emissions [1]. Based on an IPCC study, the current level of GHG needs to be reduced significantly to limit the temperature increase to 2 °C above pre-industrial levels [2].

The climate issue has gained increasingly higher status in many countries' energy policies. One example is the ambitious targets set by the European Union (EU), also known as the 20–20–20 targets. According to these, GHG must be reduced by 20%, the share of renewables increased by 20%, and primary energy use cut by 20% [3]. Emission trading schemes (ETS) and green electricity certificates or feed-in tariffs are some promising measures to achieve these targets.

Figures from 2008 show that renewable energy sources (mainly hydropower) in the Nordic countries accounted for more than 60% of the total in terms of both installed capacity and generation [4]. Power generation based on nuclear and fossil fuels has a significant share in the total balance. The share of power production based on fossil fuels may be even higher during periods of low precipitation or when maintenance is carried out at nuclear facilities (as was the case in winter 2009/10 when Swedish nuclear power plants generated far below their capacities, resulting in peak spot prices). Even though the share of renewable based power generation is high in the Nordic power system, power production and use are

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still associated with CO_2 emission, particularly when marginal production is based on fossil fuels.

Based on statistical data, the transport, petroleum and industry sectors accounted for 77% of the total emissions of 51.3 million tonnes of CO_2 equivalents in 2009 [5]. With this figure in mind, it is in these sectors that mitigation measures are needed most. The emission contribution from power and heat production is quite low (also depending on how the system boundary is defined) in Norway compared to Denmark and Finland but emissions from the oil and gas sectors stand out. The Norwegian government takes the climate change issue seriously and has therefore issued a decree to reduce emissions. Proposed targets include a 30% cut in global GHG emissions by 2020 and a carbon neutral Norway by 2050 [6]. A study conducted under the supervision of the Norwegian Climate and Pollution Agency pointed out a significant potential for a lower emission in the petroleum, industry and building sectors [7]. All of the actions suggested depend on cost-effective solutions that can contribute to not only reduce Norway's emissions, but also change the current power production situation.

The Norwegian power supply system is highly dependent on hydropower, accounting for as much as 97% of the total production and making Norway one of the world leaders in renewable power production [5]. Due to the high dominance of hydropower in the Norwegian power system, there has been a belief in people's minds that electricity utilisation is more or less CO_2 neutral. This may seem correct to some extent but power production and consumption figures indicate that Norway needs its neighbours to balance both shortages and surpluses of power. The deregulation of the power market in the Nordic countries has emphasised their interdependency even more.

Nor is high dependence on hydropower always positive for producers and customers, particularly during periods of low precipitation and high demand (cold winters). This was brought home during the winter of 2011 when a new import record of 2.3 TWh was set in January (equal to the annual consumption of the city of Trondheim with a population of 174,000) [8]. It is not known how much of the imported power is based on fossil fuels. Consumers are also advised through the media to reduce their consumption in order to slow down the use of stored water in the reservoirs.

The question is whether introducing other renewable sources and energy conservation measures (ECM) would help to avoid such situations. Other renewable energy sources such as wind power, biomass and ocean energy may contribute to a more sustainable energy system not only on a national level but also in broader system perspectives. The ambitious goal set by the Norwegian government will definitely require action in this direction. The purpose of this paper is to evaluate the impact of the introduction of a policy measure to promote renewable energy in the choice of existing and future plants such as wind power (land based and offshore), biomass-fired CHP plants, tidal energy and wave energy.

2. Model

System analysis is a useful method for understanding an energy system. It also helps to show how resources may be used to satisfy certain targets, for example low overall emissions, low costs and reduced primary energy use. When conducting a system analysis, models are helpful to reflect the essential features of the system under study.

Here, an energy system optimisation model known as MODEST [9,10] is used. MODEST stands for Model for Optimisation of Dynamic Energy Systems with Time-dependent components and boundary conditions and is based on linear programming [11]. With the MODEST model it is possible to describe any energy system (heat supply system, power supply system or both) at different levels. The objective is to optimise the total system cost (the sum of all costs for fuel, maintenance and investment and other costs such as taxes and fees).

The model has been used for different types of studies such as electricity and district heating supply at local, regional and national levels. For instance, the potential global CO_2 reduction has been studied using Stockholm's district heating system as a case object [12]. MODEST has also been used to analyse the Swedish [13] and Chilean [14] power systems where the impact of industrial energy conservation measures and renewable energy respectively are highlighted.

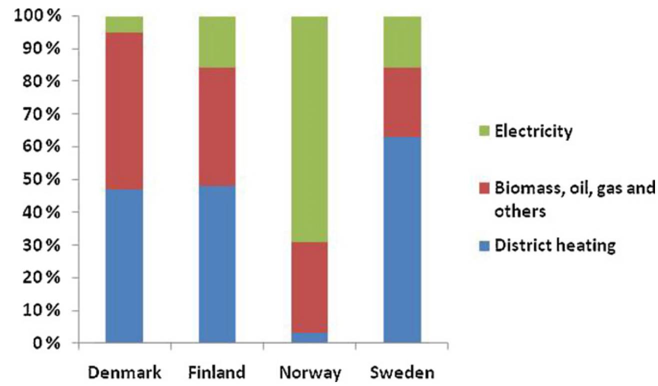


Fig. 1. Share of district heating [19].

3. District heating

The space heating sector is one of the largest consumers of energy in the Nordic countries. A district heating system (DHS) where the distributed heat is generated centrally is commonly used in these countries. One of the advantages of DHS is that it offers a substantial opportunity to incorporate different types of energy sources, for example bioenergy, solar energy and industrial waste heat. DHS also enables the use of combined heat and power (CHP) provided that heat demand is adequate. CHP is the most efficient way of reducing primary energy.

The share of district heating in the heat market is comparable in Sweden, Denmark and Finland but the situation is quite different in Norway (see Fig. 1). However, there are different reasons for development in this direction. In Norway, the abundance of hydropower together with a rather dispersed settlement pattern has in one way or another slowed the expansion of district heating. The amount of electricity used for space heating purposes is estimated to be about 30 TWh [15]. Although its share of the heat market is still low compared to the other Nordic countries, district heating is expanding in Norway. With rising energy costs and often unpredictable power prices, district heating is gaining ground. According to the Norwegian District Heating Association, the net production of district heating in 2008 was 3.2 TWh where heat production from waste accounted for more than 40% of the total [16], the remainder coming from electrical boilers (17%), biomass boilers (14%), heat pumps (10%), oil/gas boilers (11%) and waste heat (5%).

CHP production within the district heating sector varies widely in the Nordic countries. Here, Denmark and Finland have the highest share [17,18] followed by Sweden. As far as Norway is concerned, no CHP is currently available within the district heating sector (although a certain amount of electricity is generated mainly as a by-product in some waste incineration plants owned by other non-district heating producers.

District heating appears to have reached its saturation point in almost all of the Nordic countries except Norway. Hence, Norway

Table 1
Installed capacity and generation [4,20].

Type of plant	Installed capacity (MW)
Hydro power	29,474
Wind power	431
Thermal plant	890
Import/export	5240/4470

seems to have a substantial potential for greater utilisation of district heating and CHP where biomass can be used.

4. Current system

With its population of 4.9 million Norway has the highest per capita power consumption of the Nordic countries (not including Iceland). Based on statistics, the total power production and consumption were 142.7 and 128.9 TWh respectively in 2008 [4]. Regarding production, hydropower accounted for 98% of the total. The rest came from wind power and thermal facilities. According to the figures, 2008 was a year with significant exports of power to neighbouring countries. The industry sector, followed by households and the service sector, are the main power consumers. A significant amount of electricity is used for non-electricity-specific purposes, mainly heating. In this case, other energy-carriers, for example biomass, could have been used instead.

A model was set up based on installed capacities (see Table 1), annual power production and an appropriate time division. The average annual production from hydropower for the previous ten years was 123.8 TWh. The year is divided into three major periods, where the first period, representing winter, is sub-divided into fourteen sub-periods (the diurnal variation in winter is more pronounced than in other seasons) and the remaining two periods are sub-divided into four sub-periods each. This time division is chosen for simplicity and it roughly reflects the demand variation over the year. The analysis period is 10 years. The electricity demand varies from year to year but in this study a total demand of about 128.8 TWh is used (this was the demand in 2008).

5. Energy costs

As mentioned earlier, the power system in Norway is highly dominated by hydropower. Compared to other production units in the Norwegian power system, the running cost of hydropower is much lower. It is thus other costs such as power prices (for import and export) and the price of biomass that play a significant part in the optimisation.

The power market in the Nordic countries was deregulated many years ago and today there is a well-functioning power market with cross-border trading. The trading itself takes place on Nord Pool Spot, a market-place for buying and selling electricity. Although the power market is deregulated, there are still some differences in power prices within the market area (there are currently ten price areas). The yearly average spot price within the market area has varied between 30 and 54 EUR/MWh [21] over the last five years (the figures cover only the price areas in Norway, Denmark, Finland and Sweden). An average power price of 44 EUR/MWh is used here for reasons of simplicity.

Another important parameter is the price of biomass, which is a determining factor for the profitability of CHP. In this study it is assumed that biomass will cost around 30 EUR/MWh.

6. Scenarios

A number of scenarios were chosen where the focus was on determining the possible penetration of other renewable sources and energy conservation measures under various conditions. The list of scenarios is shown in Table 2.

Table 2
Scenarios.

Scenario	Description of scenario
1	The power system as it is today
2a	New plants are added to the reference system
2b	Different levels of tradable certificates are examined: 25, 37.5, 50 and 62.5 EUR/MWh
3a	Power reduction potential through energy conservation measures (ECM) low: 5 TWh
3b	Power reduction potential through energy conservation measures (ECM) high: 20 TWh
4a	Combination of 2b and 3a
4b	Combination of 2b and 3b
5a	Low precipitation (hydro power production = 106 TWh (2003)) + scenario 4a
5b	Low precipitation (hydro power production = 106 TWh (2003)) + scenario 4b
6a	High precipitation (hydro power production = 142 TWh (2000)) + scenario 4a
6b	High precipitation (hydro power production = 142 TWh (2000)) + scenario 4b

Table 3
New plants.

Type of plant	Investment cost (MEUR/MW)
Wind power, land	1.81
Wind power offshore	2.25
Wave power	4
Tidal power	4.38
Bio CHP	3.13
ECM	1.9 (assumed cost)

In scenario 2, the reference system is expanded by adding some new plants. These and their assumed investment costs are shown in Table 3. Scenarios 3a and 3b are cases based on scenario 1 but here energy conservation measures are introduced. According to a study conducted by Bellona and Siemens, as much as 20 TWh power can be saved through ECM [22]. In scenarios 5 and 6 two boundaries are investigated: low and high production from existing hydropower plants. These two extremes were registered in 2000 and 2003 [20]. ECM includes efficiency measures, energy-carrier switching and modernisation of existing production units. The specific investment costs for land-based wind power, offshore wind power, wave power and tidal power are taken from a report [23]. The costs are given in the report in Norwegian krone (NOK) but it is assumed that 1 NOK is approximately 1/8 EUR. Concerning ECM, little is known about the associated costs but a certain cost is assumed in this study.

Norway is not only blessed with an abundance of hydropower but there is also a tremendous potential as regards ocean and wind power. According to a study, there is a physical potential equivalent to 14,601 TWh from ocean energy [23]. 95% of this potential is estimated to come from offshore wind and the rest from wave and tidal energy. Based on the same study, wave power in the interval of 12–30 TWh and tidal power equivalent to 1 TWh can be exploited. In another study, the theoretical potential of tidal power is estimated to be 17 TWh [24]. For bioenergy the estimated potential is 40 TWh [15].

7. Results

This section presents the optimisation results of the studied scenarios. Fig. 2 shows the percentage share of the different sources for all the scenarios.

The result in the reference case shows that almost all the power demands are covered by hydropower production. Wind power and production from thermal plants are quite small. This is actually

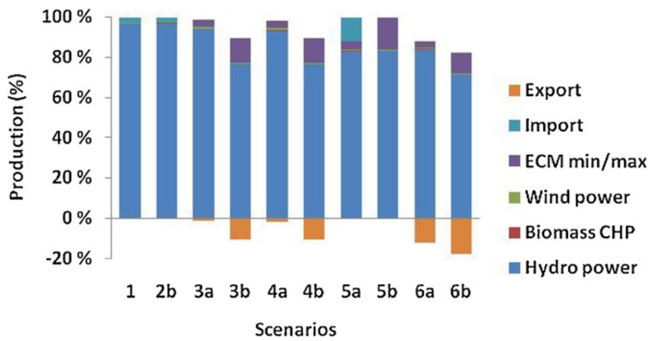


Fig. 2. Production as percentage shares (a minor share from existing thermal plants not included).

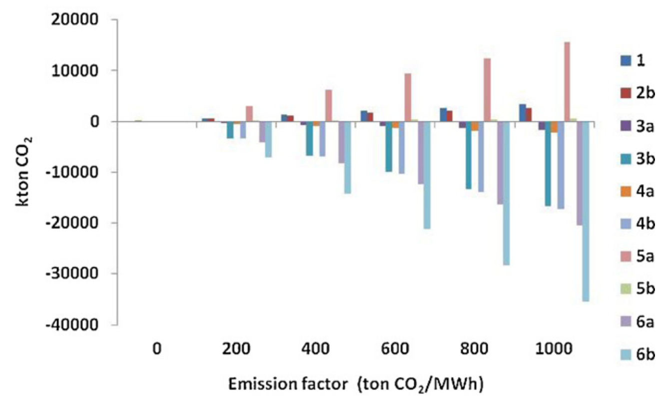


Fig. 3. CO_2 emissions.

expected and there is nothing new about it. Based on the given data, there is a net import flow to the system equivalent to 2.5% of the total demand. It should be mentioned here that the average power production from hydropower based on the last ten years is used in the model. There would have been a net export flow of power out of the system if power generation figures from 2008 were used instead.

Since hydropower is the cheapest way of producing power in the current system, none of the new plants are chosen. The system as it is modelled seems not to demand additional facilities to cover the power demand. New production units would be necessary to offset imports but this is not practicable due to the relatively high investment costs.

Tradable green certificates with a minimum value of 31 EUR/MWh seem to encourage power generation from biomass based CHP plants. The actual production depends on the size of the heat sink available. Increasing the value of the certificates from 31 to 62.5 EUR does not bring any new solution. Based on applied data, land based and offshore wind power begins to be of interest when the value of a green certificate exceeds 75 and 180 EUR, respectively.

ECM could play a substantial role in reducing the energy demand. The profitability of this measure depends on the investment required to implement it. Based on given data, this measure is profitable provided that the investment cost does not exceed 3.12 MEUR/MW. There would be a net export flow of electricity as a result of this measure.

Having both tradable green certificates and ECM simultaneously would mean that the minimum value of the tradable certificates needs to be higher than 37.5 EUR/MWh for biomass based CHP to be of interest. Increasing both the value of the certificates and the potential energy saving does not bring any new solution.

ECM mainly and new biomass CHP could play a substantial role during periods of low precipitation. Low hydropower production is compensated by these two measures and the need to import is kept at a minimum if the higher ECM limit is applied. During periods of high precipitation, ECM mainly and new biomass CHP are still profitable. In this case, very large amounts of electricity will be exported.

It is somewhat difficult to make a statement about emissions as the result of power production and consumption. As is well known, the Norwegian power system is part of the Nordic system where a significant amount of production is based on fossil fuels. In this context, imports and exports of power within the region play a vital role in terms of both efficient utilisation of resources and the environment. The environmental impact of power production and use depends on the accounting method used. Dotzauer discusses some CO_2 accounting methods, such as, average and marginal electricity [25]. In this study, emission factors in the range of 0–1000 kg CO_2/MWh are assumed (thus covering the two extreme values) to quantify the emissions for the different scenarios. The results are presented in Fig. 3. As can be seen, high energy conservation measures (ECM) together with high precipitation (scenario 6b) will give the highest emission reduction when a broader system perspective is applied. Low precipitation together with low ECM (scenario 5a) will on the other hand result in increased emissions as a result of import dependency.

8. Concluding discussion

Based on applied data, the Norwegian power system seems to have sufficient capacity to meet domestic demand. This is particularly true in times of good precipitation where production from hydropower is so high that the power system becomes a net exporter. In a system with a high dependency on hydropower, it is hard to justify new production facilities as economically viable solutions. One should also take into consideration the fact that Norway has additional exploitable hydropower resources equivalent to 33 TWh, about 10% of which are now under construction or have been granted building permits and licenses have been applied for another 20% [20]. This can also hinder the entrance of other renewables. Furthermore, the fact that the power systems are interconnected makes it difficult for new renewable facilities to enter the system even when precipitation is low (in this case the Norwegian system tends to rely on imports to balance the shortage). The need for new production units can only be justified in broader system perspectives where environmental issues carry considerable weight.

Tradable green certificates may help promote the integration of other renewable sources. Since the applied investment costs are quite high, there seems to be a need for a relatively high certificate value or other forms of incentives for more wind power and other renewable forms of energy to enter the system. Based on applied data, biomass based CHP appears to be the only type of facility that can easily enter the system with a reasonable certificate price. The newly signed agreement on common tradable green certificates between Norway and Sweden will of course play a vital role in the development of renewable energy in these countries in a broader system perspective.

Energy conservation measures (ECM) can play a major role in shaping the Norwegian power system in the direction of a more sustainable system. Reducing the country's energy use and shifting towards less electricity dependency will be viable alternatives to new generation. This will also help secure energy supply and reduce CO_2 emissions on the continent. This is particularly true if marginal power production is based on coal.

Finally, Norway has a substantial renewable energy potential and this potential can be of great importance not only on the national level but also on the continental level. This is particularly

important in Europe, where the need for lower dependence on fossil fuels is at its climax from the point of view of both supply security and the environment. It is therefore essential that a broader perspective be applied and cooperation in the energy sector increase when developing the potential renewable energy sources.

This case study is based on assumed data and a number of simplifications have been made to describe the system. The results should therefore be interpreted with this in mind. However, the model study is adequate for drawing some conclusions of relevance within the boundary conditions set.

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